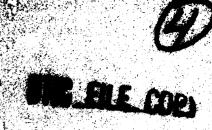


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25 March 1968

Prepared for
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AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Base
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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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PREFACE

At JPL, special thanks are due to Jim Coss, SEU group leader; the members of the beam team, Carl Malone, George Soli, and Mark Huebner; the device test engineers, Harvey Schwartz, Kevin Watson, and Peter Wang; and the able logistics and trouble-shooting efforts of Mike Havener. The Aerospace authors would like to thank Jon Osborn for producing fast RAM and microprocessor testers, and John Elder for writing extensive software to exercise the test devices, as well as for providing generous help in the analysis of the test results. Thanks are also due to Mike Marra and Bob Walter of Aerospace for constantly updating the experimental hardware and transporting it in good condition to the test site.

Special thanks are due to Ruthmary Larimer and the rest of the staff at the LBL 88-inch cyclotron and to Peter Thieberger and his staff at Brookhaven National Laboratories.

The research described in this paper was performed in part by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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I. INTRODUCTION

An ongoing single event upset (SEU) program at JPL and the Aerospace Corporation is continuing in order to assess specific parts performance in interplanetary and satellite environments and to establish trends in SEU response of many parts types.

In 1985, Nichols et al (Ref. 1) published a nearly comprehensive listing of SEU test data for 186 parts. This large collection was sufficient to permit generalizations about the parts SEU susceptibility according to their technology, function, and manufacturer.

In this report generalizations are extended to newer classes of parts and the statistical base for some of the previous parts classifications is expanded.



II. ORGANIZATION AND SCOPE OF DATA

This report presents soft error and latchup experimental test data from the Jet Propulsion Laboratory (JPL) and the Aerospace Corporation during the period from May 1985 through December 1986. However, data taken for the CRRES satellite ground test program, and proprietary data taken by DNA subcontractors and others is excluded from this survey. Much smaller data sets have been generated by other U.S. and foreign researchers; these data have not been sought for inclusion in this compilation. The data presented here, nevertheless, represent a substantial majority of all test data obtained throughout the world during this period.

The data from JPL and the Aerospace Corporation are presented in two different groups, and there are minor differences in the format of each organization. JPL defines the threshold LET as that value of LET where soft errors are first counted at fluences of approximately 10⁶ ions/cm². Aerospace defines this threshold as occurring at that LET where the measured upset cross section is 10% of the measured maximum cross section. These two values may be very different. To obtain SEU rates for a prescribed radiation environment, one requires a plot of cross section vs. LET, provided by the parent test organization.

The JPL data are conveniently divided into two tables; Table 1 for MOS devices and Table 2 for bipolar devices. The Aerospace data are given in Table 3 for all technologies. All data listed here represent a substantial abbreviation and ignore statistical features altogether. Hence, a system designer interested in a specific part is urged to contact the appropriate test organization for further information.

Data for the CRRES spacecraft program are stored at JPL, with most of the data presently available to the public.

A. TRENDS

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JPL DATA

Several interesting trends emerge from this set of data. We see (as indicated before in Ref. 1) that the CMOS RAMs have a varying susceptibility to soft errors as demonstrated by the wide variation in threshold LET; the single bipolar RAM reported here is very soft, as expected. Of special note is the fact that an epi-CMOS part exhibited latchup, reported in Ref. 2.

The single test of a PMOS technology register shows that it has a significantly higher threshold LET than the NMOS devices (DRAMs). However, more testing of PMOS technology is required to establish whether PMOS technology is harder than NMOS technology in general.

The NMOS DRAMs are very susceptible to heavy ion upset and much more susceptible than the 4k KMOS DRAM (MCM6605A) reported earlier (Ref. 1) for which the threshold LET was 14 MeV/mg/cm². One can assume that the high density (large number of bits) for the recently tested parts is relevant. It is also noted that the cross sections for the 256k DRAM can exceed the geometrical area of the sensitive regions. This observation strongly implies that multiple upsets can occur in these devices for a single ion strike. The DRAMs are so sensitive, in fact, that a test with protons or neutrons is recommended to assess their SEU response for avionics, as well as low earth orbit and space applications.

Several PROMS were tested during this period and the data support the expectation that transient upset pulses can occur in PROMs for the heavier ions. Unfortunately, the upset threshold LET was not determined in any of these tests. Note also that latchup was observed in one of the bulk CMOS PROMs at an LET of 14 MeV/mg/cm^2 .

All of the CMOS microprocessors are very soft except for the Harris 80C85 which is an equivalent to a specially hardened microprocessor of the Sandia 3000 series.

Four low power TTL bipolar logic devices were tested, which exhibited good resistance to single event upsets. Noteworthy is the fact that two older

(1974) versions of the 54L93 counter and the 54K73 flip-flop were softer than their newer (1982) equivalents, fabricated by the same manufacturer. This result contrasts with the normal trend where newer equivalent devices are usually more SEU susceptible.

For the first time, data is available on some analog-to-digital (A/D) and digital-to-analog (D/A) converter parts. This limited data subset suggests that A/D converters are more SEU susceptible than the D/A converters.

AEROSPACE DATA

The Aerospace data show that two NMOS RAMs, a TTL RAM, and an advanced CMOS technology RAM are all very susceptible to soft errors. The data show that CMOS/SOS and CMOS/epi devices are much harder, as expected.

Preliminary results for a large collection of logic devices show 54AHCTXXX devices are hard whereas 54ASXXX technology is fairly soft. The latter technology resembles the response for 54ALSXXX devices reported earlier (Ref. 1).

III. CONCLUSIONS

The new data presented here, when combined with earlier published data, (Ref. 1) list key SEU device response parameters for some 240 device types. That data base permits many useful generalizations and trends to be established. The data can be used to eliminate unacceptable device technologies and to identify for systems those key parts that are expected to be most SEU susceptible.

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- 2. K. K. Nichols, W. E. Price, M. A. Shoga, J. R. Duffey, W. A. Kolasinski, R. Koga, "Discovery of Heavy-ion Induced Latchup in CMOS/epi Devices," IEEE Trans. on Nuc. Sci., NS-33, No. 6, 1696 (Dec. 1986).

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				Threshold**	Threshold** Davice Cross*** Cross Section	Gross Section Per Bit		
Device Punction	Technology	Mfr.	art.	(MeV/mg/cm ⁻)	(Kr or Br)	(10 ° ca*)	Pacilityess	Least's
HC6167R 2AM	CHOS/RESISTOR	Honeywell	16K	>120	•	•	THE	No Latchup (435 Kobs
4046514 RAH	CHOS/EPI(%)	Barris	16K	62 >	5 x 10 ⁻²	300	UCB-68 is, SML	Six out of 11 parts latened up with Kr. Br at a > 0
IDI 6316 DAK	2003	Harris	16K	41	•	•	UCB-68 18	up with Kr, Sr at 0 > 0 Latches up with Ar and Kr
V1608 RAH	SOCO	D L	16K	21	2 x 10 ⁻²	120	MI	•
D465262 RH RAN	CHOS/EP1	Harris	16K	20	10-2	9	UCB-68 1a	
IDT 6116 RAH	Ida/Som	101	16K	r	7.2 x 10 ⁻²	9	M	
AM32244 RAH	\$0 9	AND	¥	1.6	0.41	104	ORSAY	
AN211.47 RAN	80981	AMD	¥	41.6	0.41	104	ORSAY	
AK2813 FIF0 REG.	PNOS	OK7	288	10	6 x 10 ⁻³	2000	UCB-68 18	
HT1256 DEAN (ZCL.)	SOION	Micron Tech	393K	\$	10-2	M/A	TM.	ECL logic reduces upset rate
MT1257 DEAN	SOUM	Micros Tech	256K	62	9.0	250	3 MC	
H41256 DEAN	8000	ATT	256K	2	0.5	200	JM.	
MB61256 DRAH	HNOS	Pujitau	256K	7	0.1	04	PMT.	
NOTATE	SCHOK	Intel	94K	69	10-4	•	UCA-48 1m	
PLOM	SOO	Intel	64K	417	1.5 x 10 ⁻³	•	, i	
PION	CHOS	Intel	¥ 9	•	•	•	Time	Latchup threshold -
ID6616 PROM	SOID	Harris	3 X	45	. 2-01	•	UCI-68 1s)

Some thinner epi versions, tested later, ** LET is Linear Energy Transfer or dE/dx. Threshold is the condition for no upsets for fluences > 10⁶ ions/cm².
*** The cross section (upsets/fluence) is given for 120-300 MeV krypton or bromine ions at normal incidence, having an LET ** 39 MeV/(my/cm²).
**** BNL is Brookbaven National Laboratory, UCS-88 in. is a cyclotron at Lavrence Berkeley Laboratories, Orsay is a now shut-down cyclotron at the Institut
de Physique Muclesire, Orsay, France.
This is a much tested part, having several different epi versions, discussed in another paper in this journal. Some thinner epi versions, tested later
are immune to latchup.

Recent JPL SEU Data (MOS Devices) (continued)

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Latenup with Kr at 0 degrees	UCB-68 in	•	•	<37	•	4	CHOS	Multiplier	ADSP-1016A
Partial characterization	BUL	650	4 x 10-3	<11>	009	Intel	143/5010	Microprocessor	80CB6
Equivalent to Sanota \$A3000	114	•	No upset	\$1¢	93	Marris	CHOS	Microprocessor CHOS	8008
up with 16 MeV boron (LET = 3 MeV/mg/cm²)	i	,		•	2	2			
Commercial Mask "C" latenes	136	•	•	n	· 368 <	MSC	CHOS	Microprocessor	320016
Only Div 2 and reset f/F	UCB-68 in	•	> 3 x 10-4	٠	*	NSC	Bipoler	Timing Control	NS32201
taled registers were		•) OT M B	9	9576	200	SEE.	FIGE FT. UBIL.	T90766W
				,			•		
Extrapolated Cross Section	UCB-68 in	•	2 x 10-2	ទ	>368	NSC	\$040	Microprocessor	MS32016
Extrapolated Cross Section	UCB-68 1m	•	4 x 10-3	<2.8	126/256	Intel	SOM	Mcroprocessor	808
Resert o	Pacilityees	(10 ° cs*)	(Kr or Br)	(MeV/mg/cm ⁻)			Technology	Punction	Device
		Cross Section	Thresholds* Device Cross*** Cross Section LET , Section (cm²) Per Dig	Thresholds:	# #	Mfr.			
	ned)	cross Section	1. Recent JPL SEU Data (MOS Devices) (continued) Threshold** Device Gross** Gross Section LET , Section (cm²) Peg Big	SEU Data Threshold**	lecent JPL	Table 1. F	Tal		
	ned)	cross Section	(MOS Device Device Grosses Section (cm ²)	SEU Data	lecent JPL	•	Tal		
	ned)	contin	(MOS Device	SEU Data	lecent JPL	1	Tal		

** LET is Linear Energy Transfer or dE/dx. Threshold is the condition for no upsets for fluences < 10⁶ ions/cm².
*** The cross section (upsets/fluence) is given for 120-300 MeV krypton or broains ions at normal incidence, having as LET ** 39 MeV/(ng/cm²).
*** BML is brookhaven National Laboratory, UCB-88 in. is a cyclotron at Lawrence Berkelsy Laboratories, Orsay is a now shut-down cyclotron at the Institut
de Physique Nucleaire, Orsay, France. This bipolar device is included as part of MS32016 peripherals

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Table 2. Recent JPL SEU Data (Bipolar Devices)

					Threshold**	Threshold** Device Cross*** Cross Section	Cross Section		
Device	Function	Technology	Mfr.	Bits	LET Section (cm (MeV/mg/cm ²) (Kr or Br)	Section (cm ²) (Kr or Br)	Per Bit (10-8 cm ²)	Facility	Remarks
\$4L73 (new)	54L73 (new) J/K Flip-Flop	1,111	1.1.	3	90	No upset		UCB-88 in	Date Code 8251
\$4L73 (old)	54L73 (old) J/K Flip-Flop	נ/דדנ	1.1 .	4	30	5-:01	2500	UCB-88 in	Vintage 1974
54L93 (new) Counter	Counter	L/TTL	1.1.	4	30	ı	•	BNL	Date code 8246
54193 (old) Counter	Counter	L/TTL	1.1.	4	12	4.5 × 10 ⁻⁴	10,000	BNL	Vintage 1974
931.422	RAM	ר/דנר	АМО	ΙK	43	4 x 10-2	000*	UCB-88 in	Retest
AH6012	DAC	Bipolar	GH/V	ı	15	10- 6	1	UCB-88 in	
795QV	DAC	Bipolar	QΨ	•	15	9-01	•	UCB-88 in	
, AD573	A/D (10-bit)	Bipolar	VΩ	•	\$	ı	1	UCB-88 in	Part area > Beam area
MN5253	A/D (12-bit)	Ripolar	Micro-	ı	\$ \$\$	•	•	UCB-88 in	Part area > Beam area

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TABLE 3. RECENT AEROSPACE SEU DAIA (CMOS and Bipolar Devices)

Device Paretien Technology Mfr. Site (New/Ardres) (Green) (G	Function Techn Hicroprocessor CHOS/ Hicroprocessor CHOS/ HAM CHOS/ RAM CHOS/ COTAL LATCH Adv. COTAL D-FF Adv. COTAL LATCH CHOS/ COTAL LATCH CHOS/ RAM CATE HOND COUNTER HOND SHIFT REC. HOND SHIFT REC. HOND COTAL D-FF HOND DUAL D F/F HOND SHIFT REC. HOND COUNTER HOND	1						
	Microprocessor		9 1 C •	(MeV/mg/cm²)	(Kr or Br)	(10-8 cm ²)	Facility	Rearts
Decided Control Cont	RAM CHOS RAM NHOS RAM NHOS RAM CHOS COTAL LATCH Adv. COTAL LATCH Adv. COTAL LATCH Adv. COTAL LATCH CHOS COTAL LATCH CHOS COMPARATOR CHOS COMPARATOR CHOS COMPARATOR CHOS COMMERT REC. CHOS SHIFT REC. CHOS SHIFT REC. CHOS COUNTER COU	Narria Sandia		30 30, 60	varies		UCB 88-1n. UCB 88-1n.	5V, 10V bias, respectively
December No.	RAM	22	1 5K	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	No uppet	•		
DATE March March	RAH NOS RAH Adv. RAH CHOS RAH REG CHOS RAH COPPARATOR CHOS RAH COPPARATOR CHOS RAH REG CHOS RAH CHO	SOWI	. Y 99	7	2	3125		Multiple SEU's: Latchup
Main	RAH CHOS COTAL LATCH Adv. COTAL LATCH CHOS COHPARATOR HCHOS COUNTER HCHOS LINE DRIVER HCHOS COUNTER HCHOS CHOS HCHOS CHOS HCHOS COUNTER COUNT	INMOS	94K	. 0	0.1	156		Latchup
Mail	RAH CHOS COTAL LATCH Adv. COTAL LATCH CHOS CONFARATOR HCHOS CONFARATOR HCHOS COUNTER COUNTER COUNTER COUNTER COUNTER COUNTER COUNTER CO		<u>×</u>		3 - 01 - t	2		Larchus
MAN CHOS/FET Honeywell 15K 280 No upset 0 0 0	RAM CHOS, RAM CHOS, RAM CHOS, RAM CHOS, RAM CHOS, RAM CHOS, DRAM MHOS EFFOM MHOS EFFOM MHOS CCTAL LATCH Adv. COMPARATOR HCHOS COUNTER HCHOS LINE DRIVER HCHOS LINE DRIVER HCHOS LINE DRIVER HCHOS CCTAL D-FF HCHOS CCTAL D-FF HCHOS BUSL TRANSCEIVER HCHOS COUNTER HCHOS CO		168	· <u>~</u>	9-01 × 9.5			
NAME	RAH CHOS CCTAL LATCH Adv. CCTAL LATCH Adv. CCTAL D-FF Adv. CCTAL LATCH Adv. COHPARATOR HCHOS COUNTER HCHOS COUNTER HCHOS CCTAL D-FF HCHOS CCOUNTER HCHOS COUNTER HCHOS COU	Honevuell	¥91		No upset	. 0		
DAM	RAH CHOS RAH TTL RAH CHOS RAH CHOS RAH CHOS RAH CHOS RAH CHOS RAH CHOS CCTAL J/K FF Adv. CCTAL D-FF Adv. CCTAL LATCH Adv. CCTAL LATCH Adv. CCTAL LATCH Adv. CCTAL LATCH CAVO CCTAL LATCH CONO CCTAL LATCH CONO CCTAL LATCH CONO CONFART CONO CONOTER CONO CONOTER CONO CONOTER CONO CCTAL D-FF CONO CCTAL D-FF CONO CCTAL D-FF CONO CONOTER CONO CONOTER CCOO CCTAL COO CCTAL	Harris	¥5	0,	6.5 x 10-8	•		Add. Latch error only .
DRAM	NAME	Harria	, P	>80 >80	No see a			
DUAL J/K FF MoS Mo	RAH NHOS RAH NHOS BAH NHOS EEFRON NHOS CCTAL LATCH Adv. CCTAL LATCH ACHOS CCTAL LATCH ACHOS CONTARTER HCHOS COUNTER HCHOS LINE DRIVER HCHOS LINE DRIVER HCHOS CONTER HCHOS DUAL DFF HCHOS DUAL DFF HCHOS DUAL DFF HCHOS COUNTER HCHOS COUNTER HCHOS DUAL DFF HCHOS COUNTER HCHOS COUNT	- CAY	<u> </u>	7	2 × 10-5	0007		Variant of 93L422
DRAM NHOS Fulitau 236 K 2.5 -0.2 UGB	DRAH NHOS	2	6.4K	. ~		95		
DRAM	DRAH NHOS EEFRON NHOS DUAL J/K FF Adv. OCTAL LATCH Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL LATCH Adv. SRIFT REG HCHOS OCTAL LATCH Adv. SRIFT REG HCHOS OCTAL LATCH Adv. COTAL LATCH Adv. SRIFT REG HCHOS OCTAL LATCH HCHOS UNAND GATE HCHOS DECODER HCHOS SRIFT REG. HCHOS SRIFT REG. HCHOS LINE DRIVER HCHOS LINE DRIVER HCHOS LINE DRIVER HCHOS OCTAL D-FF HCHOS DUAL D-FF HCHOS DUAL D-FF HCHOS DUAL D-FF HCHOS DUAL D-FF HCHOS EMCRODER HCHOS COUNTER HCHOS DUAL D-FF HCHOS SRIFT REG. HCHOS SRIFT REG. HCHOS SRIFT REG. HCHOS OCTAL D-FF HCHOS COUNTER HCHOS COUNTER HCHOS SRIFT REG. HCHOS COUNTER HCHOS COUNTER HCHOS COUNTER HCHOS COUNTER HCHOS SRIFT REG. HCHOS COUNTER HCHOS COUNTER HCHOS COUNTER HCHOS SRIFT REG. HCHOS COUNTER HCHOS COUNTER HCHOS COUNTER HCHOS SRIFT REG. HCHOS	Marconi	¥7	· 02	7 × 10-4	9		
DUAL JIK FF	EFFRON MHOS DUAL J/K FF Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL D-LATCH Adv. SHIFT REG HONO OCTAL LATCH Adv. SHIFT REG HONO OCTAL LATCH HONO UND AND GATE HONO DECODER HONO SHIFT REG. HONO LINE DRIVER HONO LINE DRIVER HONO OCTAL D-FF HONO OCTAL D-FF HONO DECODER HONO OCTAL D-FF HONO OCTAL D-FF HONO DALL D-FF HONO DALL D-FF HONO DALL D-FF HONO DALL D-FF HONO OCTAL D-FF HONO OCTAL D-FF HONO DALL D-FF HONO DALL D-FF HONO DALL D-FF HONO OCTAL D-FF HONO DALL D-FF HONO DALL D-FF HONO OCTAL D-FF	Suffren	256 K	7.2	2.6		UCB 88-1n.	Mulciple upsets per
DUAL J/K FF	DUAL J/K FF Adv. OCTAL LATCH Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL D-LATCH Adv. SRIFT REC HONO PARITY CHECKER HONO OCTAL LATCH HONO COMPARATOR HONO COMPARATOR HONO OCTAL LATCH HONO DUAL J/K F/F HONO SMIFT REC. HONO LINE DRIVER HONO LINE DRIVER HONO LINE DRIVER HONO OCTAL D-FF HONO DUAL D F/F HONO DUAL D F/F HONO DUAL D F/F HONO COUNTER HONO OCTAL D-FF HONO OCTAL D-FF HONO DUAL D F/F HONO COUNTER HONO OCTAL D-FF HONO OCTAL D-FF HONO DUAL D F/F HONO COUNTER HONO OCTAL D-FF		:		;			atrika
DUAL J/K FF	DUAL J/K FF Adv. OCTAL LATCH Adv. OCTAL D-FF Adv. OCTAL D-FF Adv. OCTAL D-LATCH Adv. SRIFT REG HCHOS PARTITY CHECKER HCHOS OCTAL LATCH HCHOS COMPARATOR HCHOS OCTAL LATCH HCHOS COMPARATOR HCHOS MAND GATE HCHOS UAND GATE HCHOS UAND GATE HCHOS SWIFT REG. SKIFT REG.	SEEQ	16K	7	2 × 10-4	-	UCB 88-1n.	Write/erase errors only
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Name	SHIFT REG PALITY CHECKER HCHOG OCTAL LATCH HCHOG OLOD GATE HCHOG DUAD AND GATE HCHOG DUAD AND GATE HCHOG DUAD AND GATE HCHOG OUNTER HCHOG SHIFT REG, HCHOG LINE DRIVER HCHOG ULINE DRIVER HCHOG ULL DFF HCHOG ULINE DRIVER HCHOG ULINE HCHOG UNTER HCHOG ULINE HCHOG UL		•	28		375		
PARITY CHECKER HCHOS T.I. \$ 40 \$ 4 × 10^-9 \$ 100 OCTAL LATCH HCHOS Supertex \$ 180 No upset 0 UCB OCTAL LATCH HCHOS T.I. \$ 100 0 UCB COMPARATOR HCHOS T.I. 0 UCB NAND GATE HCHOS RCA 0 UCB QUAD AND GATE HCHOS RCA 0 UCB QUAD AND GATE HCHOS RCA 0 UCB DUCO. J. K F /F HCHOS RCA 0 UCB DUCO. R. KA RCA 2 x 10^-4 2 200 UCB SHIFT REC. HCHOS RCA 8 KCA 0 UCB UCB SHIFT REC. HCHOS RCA 8 KCA 0 UCB UCB LINE DRIVER HCHOS RCA 8 KCA UCB UCB LINE DRIVER HCHOS RCA 8 KCA UCB UCB BUST TAMSCEIVER HCHOS RCA 8 KCA UCB BUAL DFF HCHOS RCA </td <td>PARITY CHECKER OCTAL LATCH OCTAL LATCH COMPARATOR NAMD GATE HEX INVERTER QAAD AAD GATE NAMD GATE DAA! J/K F/F DECODER COUNTER SHIFT REG. SKIFT REG. LINE DRIVER LINE DRIVER LINE DRIVER LINE DRIVER LINE DRIVER LINE DRIVER BUS TRANSCEIVER NOR GATE OCTAL D-FF ENCODER COUNTER SHITT REG. SKIFT REG. SKIFT REG. SKIFT REG. SKIFT REG. COUNTER SHIT REG. SKIFT REG.</td> <td>1.1.</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>Latchup (LET ~55)</td>	PARITY CHECKER OCTAL LATCH OCTAL LATCH COMPARATOR NAMD GATE HEX INVERTER QAAD AAD GATE NAMD GATE DAA! J/K F/F DECODER COUNTER SHIFT REG. SKIFT REG. LINE DRIVER LINE DRIVER LINE DRIVER LINE DRIVER LINE DRIVER LINE DRIVER BUS TRANSCEIVER NOR GATE OCTAL D-FF ENCODER COUNTER SHITT REG. SKIFT REG. SKIFT REG. SKIFT REG. SKIFT REG. COUNTER SHIT REG. SKIFT REG.	1.1.						Latchup (LET ~55)
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COMPARATOR MCHOS T.1. NAMD CATE HCHOS RCA DACODER HCHOS RCA DACODER HCHOS RCA SHIFT REC, HCHOS RCA SHIFT REC, HCHOS RCA LINE DRIVER HCHOS RCA BUS TATASCEIVER HCHOS RCA NCA NOR CATE HCHOS RCA SHIFT RCA DACODER HCHOS RCA BUS TATASCEIVER HCHOS RCA SHIFT RCA DACODER HCHOS RCA DACODER HCHOS RCA BUS TATASCEIVER HCHOS TATASCEIVER HCHOS BUS TATASCEIVER HCHOS RCA	COMFAATOR NAMD CATE NEX INVERTER QUAD AND CATE NAMD CATE DUAL, JAK F/F DECODER COUNTER SHIFT REG. SHIFT REG. SHIFT REG. LINE DRIVER LINE DRIVER NOR CATE OCTAL D-FF B-11 COMPAATOR DUAL D F/F EMCODER COUNTER SHIFT REG.	Supertex	•••	.80	No upset	0		•
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⁽¹⁾ Latchup test only at 90°C. No latchups observed with krypton.
(2) Latchup test only at 25°C. No latchup observed with krypton at 60° angle.
(3) Latchup test at 25°C and 90°C. No latchup observed with krypton at 60° angle.

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, chemical dynamics, environmental chemistry, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed chemical and excimer laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, apace vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, microelectronics applications, communication protocols, and computer security.

Electronics Research Laboratory: Microelectronics, solid-state device physics, compound semiconductors, radiation hardening; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; microwave semiconductor devices, microwave/millimeter wave measurements, diagnostics and radiometry, microwave/millimeter wave thermionic devices; atomic time and frequency standards; antennas, rf systems, electromagnetic propagation phenomena, space communication systems.

Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; non-destructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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